Review of Wind Calculations Performed Using the Federal Renewable Energy Screening Assistant and Preliminary Screening for the Eastern Neck National Wildlife Refuge, Maryland.

Patrick Cushing

Office of Science, Energy Research Undergraduate Laboratory Fellowship (ERULF)

James Madison University

National Renewable Energy Laboratory

Golden, Colorado

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Participant: ______________________________
Signature

Research Advisor: ______________________________
Signature

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Abstract

Review of Wind Calculations Performed in the Federal Renewable Energy Screening Assistant. PATRICK CUSHING (James Madison University, Harrisonburg, VA. 22807) Trina Brown (National Renewable Energy Laboratory, Golden, Colorado 80401).

The federal sector is the largest single consumer of energy in the United States. If the government can reduce its energy consumption there will be a noticeable nationwide increase in the supply of electricity. If renewable energy technologies are installed on federal sites the effect would be similar, a surplus of electricity. The Federal Renewable Screening Assistant (FRESA) was developed in order to facilitate the evaluation of these technologies for specific sites. The most current version of the software contains outdated equations and inaccurate assumptions that produce false results. The algorithms used to calculate the annual energy output were reverted to a method used in the previous version of the software. A section of code containing an unused sizing algorithm was identified and removed. Each step of the code was reviewed and documented to facilitate future changes and editing. The Hybrid Optimization Model for Electric Renewables (HOMER) was used to benchmark several of FRESA's outputs.

Category (circle one): Physical - Life – Engineering

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School Author Attends: James Madison University
DOE National Laboratory Attended: National Renewable Energy Laboratory
Mentor's Name: Trina Brown
Phone: (303)384 -7518
e-mail Address: Trina_Brown@nrel.gov

Presenter's Name: Patrick Cushing
Mailing Address: 715 South Main Street Apt. 1
City/State/ZIP: Harrisonburg, VA. 22801
Phone: (540) 801-0261
e-mail Address: cushinpa@jmu.edu

Introduction

The United States depends on fossil fuels for more than 85% of its energy production, resulting in a market sensitive to supply fluctuations and a constant risk to the nation's and world's environmental quality (1). The United States is the world's largest emitter of carbon dioxide, accounting for 28% of global CO_2 emissions (4) yet is home to only 4.5% of the global population (3). On July 23, 2001 178 countries signed the Kyoto Protocol, an international treaty aimed at reducing carbon dioxide emissions, which is the largest contributing greenhouse gas to global warming (6). The United States was the only major industrialized country that did not sign the treaty. With sustained consumption at this rate the effectiveness of any global treaty would be limited without an effort by the U.S. to reduce CO_2 emissions. In order to decrease dependence on fossil fuels and reduce carbon dioxide emissions, our nation must shift towards available renewable energy and energy-efficient technologies. With only 7.5% of total U.S. energy consumption produced by hydroelectric, biomass, wind, geothermal, and solar energy, the renewable industry has experienced a limited role in our nation's energy infrastructure (2). Despite the maturity and effectiveness of these technologies, it takes a serious and conscious effort to research and determine the best option for a specific application. In many instances, the amount of money saved will determine which options are chosen, if any. As a large, nationwide, non-profit entity, the federal government has the opportunity to lead by example and establish case-study proof of cost-effectiveness for many different renewable energy resources and energy-efficient practices. To aid federal facilities in their evaluation of the options available to them, the Federal Energy Management Program (FEMP) offers consultation, project financing, and technical assistance.

FEMP

FEMP was created to aid the federal government manage its use of energy while working to save taxpayers money through energy and water conservation (FEMP mission statement). As the nation's largest single consumer of energy, the federal government has the potential to reduce its electricity and energy demand by significant amounts. Within FEMP, there are three divisions focused on specific tasks to aid federal facilities achieve their goal of reduced energy and water consumption: project financing, technical assistance, and planning, reporting, and evaluation. Each of these divisions plays a key role in the overall mission of FEMP and depend on each other to accomplish their goals. To facilitate their role within FEMP, the technical assistance team at the National Renewable Energy Laboratory (NREL) developed the Federal Renewable Energy Screening Assistant (FRESA), a software tool that can be used by facility managers to pre-screen for 16 different energy efficiency and renewable energy options.

FRESA

FRESA was developed by FEMP in 1996 as a tool for SAVEnergy auditors to increase awareness of renewable energy among federal facilities. In recent years the program has evolved into a tool that can be used by building engineers when considering installing renewable energy or energy efficient technologies in federal facilities. FRESA is a preliminary tool that is intended to perform a pre-screen of the available technologies. The program is coded in Microsoft Visual Basic, an object oriented program with a simple user interface. The inputs required to run FRESA are basic and should already be known by the facility manager or easily obtained. Once the program has executed, a yes, no, or maybe for initial feasibility is displayed. From this screen the user can select a specific technology and take an in depth look at the results from the sizing and economic analysis performed. Because the performance of wind and solar energy depends greatly on the resource available, it is important that every federal facility wishing to install these units asses the performance for their specific location and application. Because of its easy to use nature and accessibility on the web, FRESA is a valuable tool available to both federal facilities and the private sector. However, it is important to remember that FRESA is intended to be used as a pre-screening tool only. Using it beyond its design limitations will result in misleading results. FRESA should only be used when trying to identify which renewable and energy efficient options would likely have the best economic advantages. The tool is an important asset for those interested in installing one or more of the options covered in the program. FRESA is able to provide a broad outline of what technologies are feasible and their relative costs while requiring no monetary commitment and little time. This feature allows facility managers with little to no knowledge of renewable energy to apply for funding and have a general idea of what devices are needed and how much they will cost.

In early 2001 several sections of code in FRESA were found to contain outdated calculations and inaccurate assumptions. In its present state the program is not as accurate as it could be and possibly lead building managers to eliminate options that are actually feasible and/or suggest options that would actually not be feasible for the situation. The goal of the summer research is to correct the calculations and assumptions made in the remote wind generation section of code to ensure accurate recommendations and financial estimates are produced by FRESA.

Energy from the Wind

Nearly every form of energy, including wind energy, comes from the sun. The warming and cooling of the earth's atmosphere, essentially the changes in temperature, is what drives the wind. In extreme cases this wind energy can be destructive in nature and over bearing on an environment. Fortunately, most regions on earth enjoy a moderate range of wind speeds that has allowed humans to extract energy from the wind and use it to fuel the advancement and expansion of society.

The first deliberate use of wind power by man began over 5000 years ago in the Mediterranean Sea as a means of propulsion for sailing ships (Sorensen 393). Previous vessels were limited in range by the endurance of the oar crew. With large sails, ships were able to capture energy from the wind allowing merchants to expand their trading routes and provided a military advantage to those who possessed the technology. As European societies advanced, so did their ability to harness wind energy using new and more innovative techniques. With larger and more efficient sails, European ships were able to sail across the Atlantic Ocean, colonizing the Americas.

In addition to powering sailboats, wind energy was also harnessed in the form of mechanical work for farmers. The first evidence of windmill use was by Persian societies in approximately 800 AD (Sorensen 395). The machine they used was a vertical axis design especially suited for pumping water and grinding corn. From its Persian beginnings, windmill technology spread across Europe and was improved on in the Netherlands around 1100 AD (Sorenson 396). The new design replaced the vertical axis with a horizontal axis, which has become the standard in wind turbines across the world. This new type of windmill became very popular in Europe and spread through Germany, Denmark, and Holland.

In the late 19^{th} century meteorologist Paul la Cour invented the first windmill specifically designed for electricity generation. Considered the father of wind turbine technology, la Cour is responsible for the initial research in the conversion of wind energy into electrical energy, which was beginning to play a more significant role in the global energy structure (Windpower.dk).

Since his first experimentation with electricity generation there have been many advancements in the field pushing the capacity from a few kilowatts to commercially available 2.5-megawatt turbines.

Remote Wind Generation

To perform an analysis for remote wind generation there are some basic inputs needed. From the user, an annual electricity demand, annual fuel usage, cost of fuel, and cost of electricity is entered in FRESA. Depending on which option the user chooses, the wind turbine can be analyzed as a replacement for an existing fuel generator or operate as a supplement to electricity provided by the grid. In some instances an analysis will be performed to find a turbine able to meet the entire electricity demand for a facility so it can operate without supplemental electricity form the grid. For these situations the user can enter the extra cost of the batteries, controller, wires, and installation. Other than the facility's area code, which is used to access a database of mean wind speeds, these are the only inputs required to run the remote wind generation section in FRESA.

The focus of this investigation was to review the source code for remote wind generation, turbines whose rated power falls between 600 watts (W) and 10,000 W, and identify the errors and shortcomings there within. Once these were identified, each error was researched and studied to determine what corrections needed to be made. The code was then documented and organized in order to facilitate future revisions of the program. A list of recommendations was submitted to a contracted programmer who will make the changes in the actual program.

Methodology

Before any corrections could be made to the code the errors first had to be identified. Some of the errors within the remote generation section had been previously documented, such as the calculation for the annual energy output (AEO) for the wind turbines and significantly reduced the amount of time needed in evaluating the quality of the output. By reducing the initial stages of benchmarking, the literature research became the first step in correcting the code. Once a solid understanding of small-scale wind turbines was established and access to the appropriate references was gained, revised algorithms, calculations, and constants were developed. These recommendations were inserted into a copy of the code, along with detailed documentation, and delivered to a contracted computer programmer who will then make the changes in the actual program.

Results

The code begins by defining all the variables and constants used in the program. In order to allow past users of FRESA to rerun their analysis, it was decided to keep all variables, or user inputs, the same. This limitation was decided upon and had a large impact on the options available for changing the way calculations were performed in FRESA. This was specifically an issue in determining how the AEO was to be calculated.

The method currently used to calculate the AEO for a wind turbine can be referred to as the Weibull distribution method. For every wind speed, from 0 to 25 m/s, there are a certain number of hours the wind will blow at that speed. The number of hours each wind speed blows is determined by the Weibull distribution. The Weibull distribution method is commonly used to model the wind speed at a wide range of sites (Gipe 35). In conjunction with the distribution of wind speeds, a turbine's power curve is used to calculate the AEO. The power curve is typically calculated by the manufacturer and unique to each model turbine. The power curve is basically a graph of how much energy that turbine can produce at wind speeds ranging from 0-25 m/s. If the number of hours is multiplied by the amount of energy produced at each wind speed from 0-25 m/s, then the sum of those calculations will be the AEO.

Although this method of calculating AEO is widely accepted, it is too accurate and complicated of a calculation to use in FRESA. The calculation is not executed with a power curve for each specific turbine. Instead, an approximation of the turbine's power curve is calculated based on rated power alone. Because the characteristics of a turbine's power curve defines the amount of energy it can produce, by simply estimating a power curve the accuracy of this type of calculation is neutralized. So although the Weibull distribution is commonly an accurate means of calculating AEO, it is not accurate as applied in FRESA. For these reasons a new method of calculating AEO is recommended.

The new method is based on table E-2 from Paul Gipe's *Wind Power for Home and Business*. This table provides the AEO at 30 meters above ground based on rotor diameter for each wind class. The wind classes are measured at 10 meters above ground so no adjustment is needed when using wind speeds from the database. As previously mentioned the inputs will remain constant, therefore an average rotor diameter was established based on currently available wind turbines. If the inputs are changed in future versions of FRESA, it is recommended that rotor diameter be added as one of them. A quote from Paul Gipe highlights the significance of rotor diameter in a turbine's output; "Nothing says more about a wind turbine than rotor diameter. Nothing." (Gipe 73). One of the reasons the Weibull distribution method is accurate is because the rotor diameter is intrinsic to the power curve.

In order to use the information from table E-2, it was graphed using Microsoft Excel. The AEO was plotted on the y-axis and the rotor diameter was plotted on the x-axis. This was repeated for each wind class. The polynomial trend line had the highest R^2 value and was chosen to model the data for each wind class. The equations for these trend lines are the new recommended method for calculating AEO. The AEO data given in table E-2 has all losses taken into account and is labeled as estimations only. Because FRESA is only intended to be used as a prescreening tool, this type of calculation is acceptable and can easily be modified in the future stages of editing to reflect changes in the industry.

In the current version of FRESA, the wind turbine can be sized to meet the entire electric demand of a facility or building. The sizing algorithm performed for this operation can be coded in a much simpler fashion by calculating the AEO for each of the preset wind turbines before the sizing algorithm is executed. By calculating the AEO fin the beginning of the program, a simple Boolean expression can be used to find the turbine that most closely matches the load. A more detailed explanation of this algorithm can be found in the code attached in the appendix.

For the financial analysis each turbine has its own cost per rated watt. If each turbine has its own cost per rated watt then there is no reason why a specific cost could not have been used instead. Generally the cost of wind energy decreases in larger turbine due to economies of scale. It appears the previous programmer was attempting to reflect this in the costs for the wind turbines, however the cost actually increases for the mid-range turbines and then decreases.
To reduce the complication, a cost per rated watt was recommended at $2.20 for all wind turbines. This cost was developed by averaging the cost per rated watt from 10 different wind turbines whose rated power falls between 600 W and 10 kW, the range of turbine sizes FRESA analyzes in the remote wind generation section. This cost represents a more stable cost estimation that can easily be changed as the cost for wind turbines changes.

The operation and maintenance cost for wind is recommended to be changed from $.01 per kilowatt-hour (kWh) to $.015 per kWh. Jim Green, from the National Wind Technology

Center (NWTC) recommended this as a more conservative cost estimation that better reflects the true cost of properly maintaining a small wind turbine.

The life span of a wind turbine can vary greatly depending on the local wind climate and most importantly the operation and maintenance performed on it throughout its use. Jim Green was helpful in offering his recommendations for a turbine life span and suggested a change from 25 years to 20 years. Although this may still be a somewhat generous estimation, a 20-year life span is reasonable given the increased operation and maintenance cost.

Part of the operation and maintenance of a wind turbine includes an overhaul to replace such things as bearings and other worn parts. Previously the overhauls were assumed to take place at ten and twenty years and for 5% and 10% of the initial cost, respectively. Because the life span of the turbine was recommended to be twenty years, the overhaul is should be scheduled to occur after ten years for 10% of the initial cost.

Because some areas simply do not have sufficient wind speeds for turbines, FRESA should initially check the wind speed to make sure there are sufficient wind speeds to perform an analysis. The section of code that does this is currently located at the end of the program with the financial analysis. That section has been moved to the beginning of the program and will be able to immediately identify if a wind project will be unfeasible.

In addition to the changes previously stated, large sections of code were removed from the program. These sections of code were either commented out or would no longer needed once the new recommendations are coded. The sections that were commented out served no purpose in the program and would only serve to confuse future programmers. A significant amount of documentation was added to old code and new code. A key aspect of any computer program is the ease at which it can be edit and revised.

Discussion and Conclusion

All of the recommendations made for changes in the algorithms, calculations, constants, variables, documentation, and reorganization were submitted to the project leader and are in the process of being coded by a contracted computer programmer. Once an updated version of FRESA is produced, per our recommendations, the program will hopefully be more accurate in assessing the performance of small wind turbines. Unfortunately the summer has come to an end and we are unable to see first hand the results of our recommendations. However those who work to update FRESA in the future will be able to benchmark the new version with the old and analyze the effect the changes had on the outputs. In addition, the remote generation section of the program utilizes some of the very same techniques as the utility scale section and will therefore be able to act as a guide in revising that section of code in the future. Working with the FRESA throughout the summer the importance of making the program easy to understand and edit became obvious. With further improvements FRESA will be able to supply its users with a starting point for implementing renewable energy and energy efficient technologies

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Appendix